Real Exchange Rates and Sectoral Productivity in the Eurozone

Martin Berka, Michael B. Devereux and Charles Engel*

December 23, 2013

Abstract

Abstract
We investigate the link between real exchange rates and sectoral total factor productivity measures for countries in the Eurozone. Real exchange rate patterns quite closely accord with an amended Balassa-Samuelson interpretation both in the cross-section and time series. We use a sticky price dynamic general equilibrium model to generate a cross-section and time series of real exchange rates that can be compared to the data. Under the assumption of a common currency, the model simulations closely accord with the empirical estimates for the Eurozone. Our findings contrast with previous studies that have found little relationship between productivity levels and the real exchange rate among high-income countries, but those studies have included country pairs which have a floating nominal exchange rate.

JEL classification: C51; C52
Keywords: Real Exchange Rates, Eurozone, Productivity

*Victoria University of Wellington, University of British Columbia and University of Wisconsin. E-mail addresses: martin.berka@vuw.ac.nz, devm@mail.ubc.ca, cengel@ssc.wisc.edu. Corresponding author is Engel.

1 Introduction

Understanding real exchange rate determination remains one of the most important and yet most difficult questions in international economics. The central pillar for modeling real exchange rates remains the Balassa-Samuelson model, in which persistent movements in real exchange rates over time and across countries are driven by cross-country differentials in sectoral total factor productivities. Yet it is well acknowledged that the Balassa-Samuelson model does not do well in explaining real exchange rates (e.g. Chinn and Johnston, 1996, Rogoff, 1996, Tica and Družić, 2006, Lothian and Taylor, 2008, Chong, Jordà and Taylor, 2012) except over very long time horizons. In most empirical studies, especially in time series data, the evidence for the effect of productivity growth on real exchange rates is quite weak. This problem is especially been apparent in the study of real exchange rate movements among high-income, financially developed countries.

This paper revisits the investigation of real exchange rate determination using a new data set of European price levels at a disaggregated level. Our sample of European countries allows us to construct a panel of real exchange rates at the sectoral and aggregate level in a large number of European countries over the period 1995-2009. Since the price data is in levels we can construct a real exchange rate distribution across countries at any point in time, and track the movement of this distribution over time.

Our particular focus is the properties of real exchange rates in the Eurozone, where bilateral nominal exchange rates are fixed. It is well known from modern dynamic stochastic general equilibrium models that floating nominal exchange rates are influenced by monetary policy decisions and shocks, financial shocks, and quite possibly also by non-fundamental shocks. When nominal prices adjust more slowly than the nominal exchange rate, these shocks also influence the real exchange rate. Our working hypothesis is that the real exchange rate among countries that share a common currency is more fertile ground for finding evidence of the Balassa-Samuelson effect because the short-run real exchange rate movements are not driven by these monetary and financial factors that influence nominal exchange rates.

We combine our panel of real exchange rates with measures of sectoral total factor productivities for each country, as well as a separate measure of unit labor costs. We then conduct panel regressions of real exchange rates to explore the link between the real exchange rates and productivity. Our empirical results indicate that for the Eurozone countries, there is substantial evidence of an amended Balassa-Samuelson effect. An increase in total factor productivity in traded goods is associated with a real appreciation, and an increase in total factor productivity in non-traded goods correlates with a real depreciation. But these links appear only when we separately control for unit labor cost differentials across countries. We find that, holding productivity constant, higher unit labor costs lead to real exchange rate appreciation. One interpretation for this phenomenon is that there are separate institutional forces driving factor prices, independent of factor productivities. In our theoretical model, we allow for this channel by introducing shocks to labor supply that are unrelated to productivity.

Among high-income countries with floating exchange rates, there is less evidence of a Balassa-Samuelson effect. Rogoff (1996), for example, uses relative GDP per capita as a proxy for the relative productivity in the traded sector. Rogoff finds in cross-sectional 1990 data that includes poor and rich countries, a strong relationship between relative GDP per capita and the real exchange rate[1]. However, Rogoff then notes "... whereas the relationship between income and prices is quite striking over the full data set, it is far less impressive when one looks either at the rich (industrialized) countries as a group, or at developing countries as a group."

The Balassa-Samuelson theory suggests real exchange rates should be related to sectoral total factor productivity (TFP) rather than income levels, as in the Rogoff study. There are few studies that examine the cross-sectional dimension of the Balassa-Samuelson hypothesis using sectoral data on total factor productivity (TFP), because most TFP data that is used for cross-country comparisons is in index form and is only useful for looking at the time-series dimension. The evidence favorable to

[1]Bergin, Glick, and Taylor (2006) note that this cross-sectional relationship has strengthened over time, and suggests that the tradability of goods is endogenous and may increase as a sectors productivity grows.

the Balassa-Samuelson effect is much weaker in the time-series dimension. A number of studies have looked at the relationship between productivity and real exchange rates, but can report only evidence of a long run relationship such as cointegration. Thus, Chinn and Johnston (1996) use measures of labor productivity, and find that when controlling for other variables such as government expenditure, there is evidence of cointegration of the real exchange rate and the relative productivity variable for 14 OECD countries[2]. Canzoneri, et. al. (1996) find cointegration between relative labor productivities and the real exchange rate for a panel of OECD countries.

Two recent studies examine nonlinear convergence models of the real exchange rate, relating it to relative income per capita. Lothian and Taylor (2008) use 180 years of data to find a long-run relationship between relative per capita income levels and real exchange rates among the U.S., U.K. and France. Chong et. al. (2010) examine the real exchange rates of 21 OECD countries from 1973-2008. That study uses nonlinear time series techniques to purge real exchange rates of short-run monetary and financial factors, and then finds a link between relative income per capita levels and long-run real exchange rates.

The channel through which relative productivity levels influence real exchange rates is their effect on the relative price of nontraded goods. Engel (1999) produces evidence that little of the variance of changes in U.S. real exchange rates can be accounted for by the relative price of nontraded goods. Almost all of the variance arises from movements in the consumer prices of traded goods in the U.S. relative to other countries. Several studies (e.g., Engel, 1999, Burstein et. al. 2003, 2005, Betts and Kehoe, 2006) suggest that differences in consumer prices of traded goods across countries may be accounted for by changes in the relative price of nontraded distribution services but the evidence for this hypothesis is weak for high-income countries. However, the seminal paper by Mussa (1986) has pointed out that real exchange rates are much less volatile among countries with fixed nominal exchange rates. It is this observation that motivates our study of the Eurozone real exchange rates.

[2] De Gregorio et. al. (1994) use the same TFP data and country coverage as Chinn and Johnston to examine the dynamics of the prices of nontradable relative to tradable goods.

The Balassa-Samuelson model must be modified when the exports of a country are not perfect substitutes for it imports. We show in a simple flexible-price model how differences in unit labor costs may influence real exchange rates both through their effects on the relative prices of nontraded goods and also the terms of trade. We have noted that the Balassa-Samuelson effect may be difficult to find when nominal exchange rates are volatile and goods prices are sticky. We proceed to examine the implications for the Balassa-Samuelson theory when nominal exchange rates are not volatile when countries share a common currency but nominal prices are sticky. We construct a small dynamic general equilibrium model of real exchange rates, with sticky prices and monetary policy under fixed exchange rates. We can use the model to generate a panel of real exchange rate levels and movements over time which matches the European panel for the Eurozone countries. Using the same cross-section and time series dimensions as the data, the model is simulated using shocks to sectoral productivities and labor supply shocks that proxy for independent unit labor cost shocks. We find a close relationship between the empirical estimates and the model simulation estimates. Real exchange rates in the model are driven by an amended Balassa-Samuelson pattern of shocks to sectoral productivity and unit labor costs, and the simulation estimates are quite close to those in the Eurozone data.

The paper is organized as follows. The next section sets out a basic theoretical model of real exchange rates with shocks to monetary policy, productivity and labor supply. Section 3 outlines our data, and shows some properties of European real exchange rates for the Eurozone and non-Eurozone countries. This section also describes the properties of sectoral productivity and unit labor costs for a restricted sample of countries. We provide empirical estimates of an amended Balassa-Samuelson relationship for the Eurozone. Section 4 calibrates the theoretical model, and performs the same regressions on simulated data as were done with the data. Some conclusions follow.

2 Real Exchange Rates in a Theoretical Model

2.1 A Basic New Keynesian model

Our data is a balanced panel of European country real exchange rates. In the model simulations, we construct a panel of equivalent dimensions. But the theoretical explication of the model can be developed using the standard two-country DSGE approach. Let these countries be called 'home' and 'foreign'. We primarily present equations for the home country. Equations for the foreign country are symmetric to those for the home, and foreign variables are denoted with a *.

The utility of a representative infinitely lived home country household evaluated from date 0 is defined as:

$$U_t = E_0 \sum_{t=0}^{\infty} \beta^t \left(\frac{C_t^{1-\sigma}}{1-\sigma} - \Upsilon_t \frac{N_t^{1+\psi}}{1+\psi} \right), \quad \beta < 1. \tag{2.1}$$

where C_t in (2.1) is the composite home consumption bundle, and N_t is home labor supply. We allow that the disutility in labor supply Υ_t to be time-varying and country-specific. This plays a role in generating real exchange rate variability across countries and over time, as described below. The composite consumption good is defined as:

$$C_t = \left(\gamma^{\frac{1}{\theta}} C_{Tt}^{1-\frac{1}{\theta}} + (1-\gamma)^{\frac{1}{\theta}} C_{Nt}^{1-\frac{1}{\theta}} \right)^{\frac{\theta}{\theta-1}},$$

where C_{Tt} and C_{Nt} represent, respectively, the composite consumption of traded and non-traded goods. The elasticity of substitution between traded and non-traded goods is θ. Traded consumption in turn is decomposed into consumption of home retail goods, and foreign retail goods, as follows:

$$C_{Tt} = \left(\omega^{\frac{1}{\lambda}} C_{Ht}^{1-\frac{1}{\lambda}} + (1-\omega)^{\frac{1}{\lambda}} C_{Ft}^{1-\frac{1}{\lambda}} \right)^{\frac{\lambda}{\lambda-1}},$$

where λ is the elasticity of substitution between the home and foreign traded good. Home households put weight ω on home consumption goods in their consumption basket. In the foreign country, households put weight ω on foreign consumption goods. In a perfectly symmetric model, there would be no home bias in consumption if $\omega = 1/2$, but the stronger the preference of households for the good produced in their own country, the larger is ω.

Retail consumption of traded goods requires the use of non-traded goods in order to facilitate consumption, however. This can be rationalized by the argument that there are costs of distribution of traded goods, and these costs must be incurred by local (i.e. non-traded inputs). Hence, we assume that the production of consumption-related retail goods in sectors H and F are assembled according to:

$$
\begin{aligned}
C_{Ht} &= \left(\kappa^{\frac{1}{\phi}} I_{Ht}^{1-\frac{1}{\phi}} + (1-\kappa)^{\frac{1}{\phi}} V_{Ht}^{1-\frac{1}{\phi}}\right)^{\frac{\phi}{\phi-1}} \\
C_{Ft} &= \left(\kappa^{\frac{1}{\phi}} I_{Ft}^{(1-\frac{1}{\phi})} + (1-\kappa)^{\frac{1}{\phi}} V_{Ft}^{1-\frac{1}{\phi}}\right)^{\frac{\phi}{\phi-1}}
\end{aligned}
$$

where I_{Ht} represents inputs of the home export good into the retail consumption of that good, and V_{Ht} represents input of the home non-traded good into the retail consumption of the export good. The elasticity of substitution between non-traded inputs and the export good itself is ϕ. Our calibrations insection 4 will set ϕ to be fairly low, representing the fact that distribution services are not a good substitute for the actual consumption good. The notation for the retail consumption of imports (foreign goods) is similarly defined.

The consumption aggregates imply the following price index definitions:

$$
P_t = \left(\gamma P_{Tt}^{1-\theta} + (1-\gamma) P_{Nt}^{1-\theta}\right)^{\frac{1}{1-\theta}},
$$

$$
P_{Tt} = \left(\omega \tilde{P}_{Ht}^{1-\lambda} + (1-\omega) \tilde{P}_{Ft}^{1-\lambda}\right)^{\frac{1}{1-\lambda}},
$$

where P_{Tt} and P_{Nt} represent traded and non-traded price levels, and P_{Ht} and P_{Ft} are retail prices of consumption of home and foreign traded goods. Finally, these retail prices in turn depend on prices at the dock as well as the non-traded goods price. Hence:

$$
\begin{aligned}
\tilde{P}_{Ht} &= \left(\kappa P_{Ht}^{(1-\phi)} + (1-\kappa) P_{Nt}^{1-\phi}\right)^{\frac{1}{1-\phi}} \\
\tilde{P}_{F} &= \left(\kappa P_{Ft}^{(1-\phi)} + (1-\kappa) P_{Nt}^{1-\phi}\right)^{\frac{1}{1-\phi}}
\end{aligned}
$$

We assume that prices of goods at the dock are equal in the home and foreign countries in the Eurozone, so that:

$$
P_{Ht} = P_{Ht}^{*}, \qquad P_{Ft} = P_{Ft}^{*}
$$

The real exchange rate, however, may not be a constant because of prices of nontraded consumption goods and distribution services are not equalized across the home and foreign countries, and because of the possibility that consumption baskets differ. We define the real exchange rate as the price of foreign relative to home consumption

$$Q_t = \frac{P_t^*}{P_t}.$$

Note that the real exchange rate between the home and foreign country is fixed at one because countries in the Eurozone share a common currency.

We assume that international financial markets are complete. As is well known, this implies a risk sharing condition given by:

$$\frac{C_t^{-\sigma}}{P_t} = \frac{C_t^{*-\sigma}}{P_t^*} \tag{2.2}$$

Households choose consumption of individual goods and labor supply in each sector in the usual way. The implicit labor supply for home households is given by:

$$W_t = \Upsilon_t P_t C^\sigma N_t^\psi$$

where W_t is the nominal wage. The demand for traded and non-traded goods is described as:

$$C_{Tt} = \gamma \left(\frac{P_{Tt}}{P_t}\right)^{-\theta} C_t, \qquad C_{Nt} = (1-\gamma)\left(\frac{P_{Nt}}{P_t}\right)^{-\theta} C_t$$

Demand for home and foreign composite traded Goods is denoted as:

$$C_{Ht} = \omega \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt}, \qquad C_{Ft} = (1-\omega)\left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt}$$

We can express the individual consumption demand for home and foreign traded goods (net of the distribution services) as

$$I_{Ht} = \kappa\gamma\omega \left(\frac{P_{Ht}}{\tilde{P}_{Ht}}\right)^{-\phi} \left(\frac{\tilde{P}_{Ht}}{P_{Tt}}\right)^{-\lambda} C_{Tt}, \qquad I_{Ft} = \kappa\gamma(1-\omega)\left(\frac{P_{Ft}}{\tilde{P}_{Ft}}\right)^{-\phi} \left(\frac{\tilde{P}_{Ft}}{P_{Tt}}\right)^{-\lambda} C_{Tt},$$

Firms in each sector produce using labor and a fixed capital stock[3] . A typical firm in the non-traded (traded) sector has production function $Y_{Nt}(i) = A_{Nt}N_{Nt}(i)^\alpha$,

[3]The implications for real exchange rates would not differ materially were we to allow for endogenous capital accumulation.

$Y_{Ht}(i) = A_{Ht}N_{Ht}(i)^{\alpha}$. Thus, there are two technology shocks - shocks to the non-traded sector A_{Nt}, and to the traded sectorA_{Ht}. In addition to the labor supply shock Υ_t, these shocks are the key fundamental driving forces of efficient equilibrium real exchange rates in the model.

With perfectly flexible prices, assuming that each firm is a monopolistic competitor with constant elasticity of substitution between varieties within each sub-sector, a firm in the home country would set its price equal to marginal cost, adjusted by a constant markup. Thus, for the typical non-traded goods firm and a home traded goods producing firm, we have, in a flexible price environment:

$$P_{Nt}^{flex} = \Omega \frac{W_t}{\alpha A_{Nt} L_{Nt}^{\alpha-1}}, \qquad P_{Ht}^{flex} = \Omega \frac{W_t}{\alpha A_{Ht} L_{Ht}^{\alpha-1}}$$

where Ω is a constant markup, depending on the elasticity of substitution between varieties.

We assume that firms cannot reset prices freely, but rather must follow a Calvo price adjustment specification where the probably of the firm being allowed to adjust its price is $1-\zeta$ in each period. Home firms use domestic household nominal marginal utilities as stochastic discount factors. When prices are reset, firms set their price so that it is equal to a discounted present value of current and anticipated future fully flexible prices:

$$P_{Nt} = \frac{E_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau} P_{N\tau}^{flex}}{E_t \sum_{\tau=t}^{\infty} \Gamma_{N,\tau}}, \qquad P_{Ht} = \frac{E_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau} P_{H\tau}^{flex}}{E_t \sum_{\tau=t}^{\infty} \Gamma_{H,\tau}}$$

where $\Gamma_{N,t}$ and $\Gamma_{H,t}$ represent adjusted stochastic discount factors that incorporate the Calvo propbability of a firm's price staying constant each period. Foreign firms price foreign exports, P_{Ft}^{*} and foreign non-traded goods, P_{Nt}^{*}, analogously.

The countries of the Eurozone share a common monetary policy. The instrument of monetary policy is the nominal interest rate, and we assume the central bank follows an inflation targeting instrument rule. For simplicity, we assume the central bank targets the inflation rate in the foreign country:

$$r_t = \rho + \sigma_p \pi_t^{*} \tag{2.3}$$

where $\pi_t^* = p_t^* - p_{t-1}^*$ is the foreign inflation rate (and $p_t^* = \log(P_t^*)$). In practice, in simulation results, we find it makes essentially no difference if the central bank targets the home inflation rate, the foreign inflation rate, or an average.

Finally, goods market clearing conditions are given as:

$$\begin{aligned} Y_{Ht} &= I_{Ht} + I_{Ht}^* \\ Y_{Ft}^* &= I_{Ft} + I_{Ft}^*, \\ Y_{Nt} &= C_{Nt} + I_{Ht} + I_{Ft}, \\ Y_{Nt}^* &= C_{Nt}^* + V_{Ht}^* + V_{Ft}^*. \end{aligned} \tag{2.4}$$

Traded goods production must equal demand derived from home and foreign consumers' consumption of retail traded goods. Non-traded goods production is equal to that accounted for by consumers, and that used in the distribution services of traded goods, in each country.

In addition, we must have labor market clearing in each country, so that:

$$N_t = N_{Nt} + N_{Ht} \tag{2.5}$$

$$N_t^* = N_{Nt}^* + N_{Ht}^* \tag{2.6}$$

The definition of equilibrium is standard and we omit it to save space.

2.2 The Real Exchange Rate Decomposition

The real exchange rate in this model is influenced by structural differences across countries and shocks that cause relative prices to move over time. Following Engel (1999), we can write a log linear approximation of the real exchange rate in terms of differences in the relative price of non-traded to traded goods across countries, and differences across countries in the price indexes of traded goods. Our model does not allow for any pricing to market by producers. In fact, there may well be "local currency pricing" when countries use different currencies and have a floating nominal exchange rate. Here, we introduce the notation s to designate the log of the nominal exchange rate, defined as the home currency price of foreign currency. Foreign prices in this sub-section are assumed to be denominated in the foreign currency.

Omitting time subscripts for ease of notation, we have:

$$q = (1-\gamma)q_n + q_T \tag{2.7}$$

where $q_n \equiv (p_N^* - p_T^* - (p_N - p_T))$, and $q_T \equiv p_T^* + s - p_T$. Note that the first expression on the right hand side does not contain the nominal exchange rate; it is the difference across countries in the relative local currency price of non-traded to traded goods. A rise in the foreign relative price relative to the home relative price, causes a home real exchange rate depreciation. The second expression on the right hand side is the traded goods real exchange rate at the retail level. But in our model, due to distribution costs in retail, this should also be affected by the relative price of non-traded goods. To see this, we may further decompose the second expression as:

$$q_T = \frac{1-\kappa}{\kappa}(p_N^* - p_T^* - (p_N - p_T)) + (2\omega - 1)\tau + p_H^* + s - p_H \tag{2.8}$$

where $\tau = p_F^* - p_H^* = p_F - p_H$ is the terms of trade of the home country[4] and $p_H^* + s - p_H$ represents the deviation from the law of one price in home traded goods. This expression tells us that the traded goods real exchange rate is driven by a) differences in relative non-traded goods prices across countries - again a rise in this relative-relative price will cause a real exchange rate depreciation, b) the terms of trade, when there is home bias in preferences (i.e. $\omega > \frac{1}{2}$), and c) deviations from the law of one price - a higher foreign price of equivalent goods relative to the home price is associated with a real exchange rate depreciation.

Putting together these two previous expressions, we see that the nominal exchange rate directly enters the real exchange rate decomposition explicitly only to the extent that there are deviations from the law of one price. In the model described above, we do not allow for deviations from the law of one price. Our model assumes that pricing to market is no an important feature of the data within the Eurozone. Our inspiration for examining the Eurozone is the case made in Mussa (1986) and Engel (1999) that under floating rates, nominal exchange rate fluctuations play a significant role in accounting for real exchange rate movements because of sticky nominal prices

[4] This definition uses the fact that up to a first order approximation, the terms of trade facing foreign and home purchasers is the same. An identical equivalence up to a first order holds for the deviation from the law of one price for home and foreign goods. See Engel, 2011.

set in local currencies. We suspect that absent these fluctuations, we are more likely to tease out the Balassa-Samuelson effect of productivity on the real exchange rate, which operates through the relative-relative price of non-traded goods. Of course, equations (2.7) and (2.8) do not say that the only differences between real exchange rate behaviour across fixed and flexible exchange rate regimes is due to deviations in the law of one price. To the extent that the real exchange rate regime affects real variables through monetary non-neutrality, the other components of the real exchange rate will also differ across fixed and flexible exchange rates.

While this decomposition stresses the time series movement in the real exchange rate, we want to emphasize that a similar decomposition can be done in terms of the *level* of the real exchange rate between any two countries. In our analysis of the data, we do not attempt to account for any pricing to market that affects the price levels of consumer goods at the dock within the Eurozone. Our investigation will only allow for differences in consumer prices of traded goods that arise because of differences in distribution costs. A country may have a relative consumer price due to the productivity differentials that drive the relative-relative price of non-traded goods, or a high terms of trade. In our data, we see considerably persistent differentials among Eurozone members.

2.3 Relative Productivity and Real Exchange Rates

The decomposition above tells us what the channels of real exchange determination will be, but it is silent on the underlying determinants of real exchange rates. Consider a version of the theory presented above in which prices are fully flexible. The real exchange rate will be affected by shocks to productivity and by shocks to labor supply. The Balassa-Samuelson effect captures the link between relative productivity in traded to non-traded goods sectors and the real exchange rate. The standard Balassa-Samuelson mechanism implies that a rise in relative traded goods productivity causes a rise in the relative price of non-traded to traded goods (when compared across countries), leading to a real exchange rate appreciation. But when home and foreign goods are not perfect substitutes there is a countervailing effect coming from the endogenous response of the terms of trade. A rise in relative home traded goods productivity will generate a terms of trade deterioration. Conditional on the relative price of non-traded goods to domestic goods in each country, the terms of trade deterioration will lead the real exchange rate to depreciate.

Relative labor supply shocks will also affect the terms of trade and the real exchange rate. To see the different effects more clearly, we take a special case of the above model, where a) $\kappa = 1$, so there is no distribution effect on traded goods, and b) $\omega = 1$, so that there is no home bias. To economize on notation, we omit time subscripts. Take a log-linear approximation to the model under flexible goods prices, around a symmetric steady state:

$$\begin{aligned} q &= (1-\gamma)(p_N^* - p_T^* - (p_N - p_T)) \\ &= (1-\gamma)(p_F^* - p_H) + (1-\gamma)(p_N^* - p_F^* - (p_N - p_H)) \end{aligned} \tag{2.9}$$

The first expression on the second line is the terms of trade effect, while the second expression is the ratio of internal relative prices of non-traded goods and the domestic good for each country.

Now take a further special case, where c) $\psi = 0$, so that utility is linear in labor, and d) $\zeta = 0$, so prices are perfectly flexible. Then by profit maximization, it must be that, for the home country, $p_N - p_H = w - a_N - (w - a_H) = a_H - a_N$. Hence, the relative price of non-traded good to the home traded good equals relative productivity in the home traded good to that in the non-traded good. Doing the same for the foreign country, substituting in (2.9) gives us:

$$q = (1-\gamma)(p_F^* - p_H) + (1-\gamma)(a_F^* - a_N^* - (a_H - a_N)) \tag{2.10}$$

This gives us the two parts of the real exchange rate discussed above. The second expression captures the Balassa-Samuelson mechanism - a rise in home relative traded goods productivity generates a real exchange rate appreciation. The first expression captures the endogeneity of the terms of trade. In general, the trade-off between these two forces will depend on the trade elasticity λ. But in the case of complete security markets and assumptions a)-d), we can express the terms of trade in the following way (where $\chi \equiv \log(\Upsilon)$):

$$(p_F^* - p_H) = \sigma c + p - \sigma c^* - p^* + p_F^* - p_H =$$

$$w - \chi - (w^* - \chi^*) + p_F^* - p_H = \chi^* - \chi + a_H - a_F^*$$

where the first equality used the risk sharing condition (2.2), the second equality uses the labor supply equilibrium, and the third equality uses the flexible price profit maximizing condition for each country, with symmetry. This says the terms of trade under assumptions a)-d) is equal to the negative of the relative labor supply shocks, and positively related to relative traded good productivities. Substituting into (2.10) we get:

$$q = (1 - \gamma)(\chi^* - \chi) + (1 - \gamma)(a_N - a_N^*) \tag{2.11}$$

Under assumptions a)-d), the real exchange rate depends only on relative labor supply shocks, and relative non-traded goods productivity, *independent* of the size of the trade elasticity. Hence, the Balassa-Samuelson linkage from traded goods productivity to the real exchange rate disappears entirely.

This relationship has the disadvantage that it depends on the unobservables χ^* and χ. But this can be surmounted by incorporating unit labor costs in the real exchange rate productivity relationship. Take the definition of unit labor costs as the nominal wage divided by aggregate output per worker. We define unit labor cost for the home country as:

$$\text{ulc} = w - \gamma(y_H - n_H) - (1 - \gamma)(y_N - n_N) = w - \gamma a_H - (1 - \gamma) a_N$$

Relative unit labor cost for foreign to home is defined as:

$$\text{rulc} = w^* - w - \gamma(a_F^* - a_H) - (1 - \gamma)(a_N^* - a_N)$$

Using the risk sharing condition, this becomes:

$$\text{rulc} = \chi^* - \chi - \gamma(a_F^* - a_H) - (1 - \gamma)(a_N^* - a_N)$$

Substituting into (2.10) we obtain the relationship between the real exchange rate, sectoral productivities, and measured relative unit labor cost as

$$q = (1 - \gamma)\ \text{rulc} - (1 - \gamma)\gamma(a_H - a_F^*) + (1 - \gamma)\gamma(a_N - a_N^*) \tag{2.12}$$

Equation (2.12) indicates that, conditional on relative unit labor costs, the real exchange rate is negatively related to relative traded goods productivity, as implied by the Balassa-Samuelson mechanism. But under conditions a)-d), this is critically dependent on there being a separate driver of unit labor costs, captured in our model as the labor supply shocks.

In the more general model with distribution services, more general labor supply elasticities, and sticky prices, the independence of the real exchange rate from traded goods productivity as in (2.10) no longer holds exactly. But it remains true qualitatively that the presence of optimal risk-sharing dampens the theoretical linkage between the real exchange rate and traded goods productivity. This offers a rationale for the use of unit labor costs as a separate driver of real exchange rates, both in the data and the theoretical model. Much of the discussion of the evolution of real exchange rates in Europe has focused on the role of unit labor costs. Felipe and Kumar (2011) indeed document that differences in unit labor costs in the Eurozone are highly correlated with the relative price of output ($p_F^* - p_H$ above). The inclusion of the relative unit labor costs may account for the additional term in (2.9) that drives real exchange rate movements beyond the standard Balassa-Samuelson effect.

3 Data: Real Exchange Rates and Productivity

3.1 Real Exchange Rates in European Data

We describe the features of European real exchange rates based on disaggregated price data. The data are constructed by Eurostat, as part of the Eurostat PPP project. They are arranged in the form of 'Price Level Indices', or PLI's. A PLI gives the price of a good at a given time for a given country, relative to a reference country price. Hence, it is a good specific PPP, although within the Eurozone, this measure does not involve different currencies. The frequency is annual, over 1995-2009 and the PLI's are available for 146 consumer goods and services. These include food (including food away from home), clothing, housing costs, durable goods, transportation costs, as well as medical and educational services. The full list of PLI's for consumer goods is contained in Table 1. For each item, the reference price is constructed as a ratio of the European average price of each good[5]. Hence the prices are comparable in levels, so that both cross section and time series real exchange rate variation can be examined[6]. Our sample data contains 11 countries that entered the Eurozone in 1999 [7], and one that entered in 2001 (Greece)[8]. We construct aggregate and sectoral real exchange rates from the underlying price series, using expenditure weights. Let q_{it} be the average overall (log) price level (or real exchange rate, equivalently) for country i at time t, and let q_{iTt} (q_{iNt}) represent the average expenditure weighted price level of the subset of traded (non-traded) goods. As in the model, real exchange rates are measured so that an increase represents a depreciation.

We construct an aggregate real exchange rate using expenditure weights for each good. We then separate goods into traded and non-traded categories using criteria reported in the Appendix. Then using these aggregate measures, some descriptive statistics are reported in Table 2. The Table first reports the average log real exchange rate over the sample for each country in the sample, denoted $\bar{q}$, as well as the equivalent measures for the traded goods real exchange rate $\bar{q}_T$, the non-traded goods real exchange rate, $\bar{q}_N$, and also the relative price of non-traded goods $\bar{p}_n = \bar{q}_N - \bar{q}_T$.

We see from the Table that Belgium, Germany and France have average real exchange rates of close to zero, implying they are at the European average. Ireland and Finland have much higher positive real exchange rates, while Greece, Spain, Portugal and Italy, have much lower average real exchange rates. The characteristics of the sectoral real exchange rates, and the average relative price of non-traded goods closely mirror that aggregate real exchange rate characteristics. In general, we see that if for country i, we have $\bar{q}_i > 0$, (< 0), we also have $\bar{q}_{Ti} > 0$, (< 0), $\bar{q}_{Ni} > 0$, (< 0), and $\bar{p}_{ni} = \bar{q}_{Ni} - \bar{q}_{Ti} > 0,\ (< 0)$; that is, if a country has a low (high) average price level relative to the European average, its non-traded goods price tends to be

[5] The average is taken over the central 15 European countries given by; Austria, Belgium, Denmark, France, Germany, Greece, Ireland, Italy, Luxembourg, the Netherlands, Spain, Sweden, Portugal, Finland, and the United Kingdom.

[6] See Berka and Devereux (2013) for a more complete description of the data.

[7] These are Belgium, Germany, Spain, France, Ireland, Italy, Luxembourg, Netherlands, Austria, Portugal, and Finland.

[8] Note that our sample includes the period 1995-1998 before the official inception of the euro. But intra-Eurozone exchange rate fluctuations over this period were very small, with average quarterly standard deviations about 1 percent.

proportionately lower (higher) than its traded goods price, relative to the average.

The second panel of Table 2 reports standard deviations of annual real exchange rates. They are approximately 3 percent for most countries. The standard deviation of non-traded real exchange rates exceeds that of the traded real exchange rate.

Table 3 reports averages across all countries and over time. The first panel gives the average time series volatility of aggregate and sectoral real exchange rates. The second panel reports the cross country dispersion in aggregate and sectoral real exchange rates. The cross country standard deviation of aggregate real exchange rates is over 30 percent, and almost 50 percent for the non-traded real exchange rates.

Tables 2 and 3 contain some statistics for countries in Europe that have floating exchange rates. We obtain this data from the same Eurostat dataset as our Eurozone data, but the coverage of countries is limited. Still, it is interesting to compare the real exchange rate and relative price behavior in the set of floating-rate countries from Western Europe for which we have data, and the Eastern European countries as well, to the Eurozone. We see that the real exchange rates that involve using the nominal exchange rate in their calculation tend to have a higher variance in the floating exchange rate countries of both Western and Eastern Europe compared to the Eurozone. The statistics reported in Table 3 suggest that the main difference between the Eurozone and the floating rate countries of Western Europe arises from the differences in their time-series standard deviations.

In constructing the model below, we explicitly take account of both the time series and cross-section characteristics of real exchange rates, as characterized by the data.

Figures 1-2 illustrate some properties of real exchange rates in the Eurozone. Figure 1 shows the pattern of mean annual standard deviations of all consumer good PLI's separately for the Eurozone as a whole, and for two separate groups of countries. For ease of description, although somewhat inaccurately, we refer to the first group as 'Northern Europe', and the second group as 'Southern Europe'.[9]. For the Eurozone as a whole, there is a continual fall in dispersion through the sample. For the Northern group, dispersion is significantly lower, and falls over time. For the southern group,

[9]'Northern Europe' consists of Belgium, Germany, France, Netherlands, Austria, Finland, while 'Southern Europe' is comprised of Greece, Ireland, Italy, Spain and Portugal.

dispersion rises at first, but then peaks in the early 2000's, falling thereafter.

Figure 2 illustrates the mean aggregate real exchange rates separately for the Northern and Southern groups. Over the sample, there is substantial convergence towards the mean for both groups of countries. Moreover, consistent with standard theory, deviations from average are higher (lower) for the non-traded (traded) goods real exchange rates.

3.2 Productivity and Unit Labor Cost data

We compute measures of total factor productivity that match our real exchange rate sample. For this, we require TFP levels, both in the aggregate and by sector, for the same sample period as in the real exchange rate data. We do this by combining two sources for TFP. We construct a concordance between the sectors included in the Groningen Growth and Development Center's (GGDC thereafter) 1997 TFP level database, and the sectors included in the KLEMS time-series database. These two databases are meant to be used in conjunction, as outlined in Inklaar and Timmer (2008). Then, the cross-sectional TFP database and the time-series TFP database are linked using the constructed concordance to obtain annual sectoral panel TFP level data. We then use measures of the tradability of each sector and sectoral weights to construct level and time series of TFP for traded and non-traded sectors in each country. Following this, we express these measures in the same manner as the real exchange rates: TFP in the EU relative to country i TFP. As a result, we obtain a panel of traded and non-traded TFP levels which provide a match for our real exchange rate data[10]. The details of the construction are in the Appendix A[11].

Table 2 and 3 report descriptive statistics for traded and non-traded goods productivity in the same form at the real exchange rate data. In general, we see that traded goods productivity is more volatile than non-traded goods productivity.

Our theoretical model also allows for a separate driver of the real exchange rate

[10]The matching is not quite perfect, because only 9 of the Eurozone countries have TFP data: Belgium, Germany, Spain, France, Ireland, Italy, the Netherlands, Austria, and Finland.

[11]We also constructed a series for labour productivity in the aggregate and for each sector, for all countries. The contrast between the estimates of the model for TFP and for labor productivity are discussed in the Appendix.

attributable to labor supply effects, as measured by the variable χ above. We do not have direct evidence on this variable, but if there are country specific labor supply related shocks, driven for instance by labor market institutions, unionization or regulatory changes, independent of productivity, we should see this reflected in real wage movements that are not attributable to movements in TFP. We capture this possibility by including unit labor costs as a separate variable in the regressions reported below. The theoretical justification for relating χ to unit labor costs was discussed in Section 2 above. Unit labor costs (ULC) are computed from the OECD Stat database, and expressed as average ULC in the European union relative to ULC in country i (the same way as the sectoral productivity and real exchange rate data). Appendix B gives more details of the ULC construction.

Figures 3-4 illustrate the properties of traded and non-traded productivity for the subset of countries in the categories of Figures 1-2 for which we have sectoral productivity data. Figure 3 shows that traded goods productivity declined systematically for the Southern European countries over the sample, while it increased slightly for Northern Europe. Figure 4 illustrates the same series for non-traded goods productivity. Non-traded goods productivity is substantially lower in the Southern European subset of countries.

Finally, Figure 5 shows unit labor costs for the three groups of countries. For the Northern European countries, unit labor costs are essentially flat over the whole sample, while in the Southern European countries, unit labor costs are initially much lower, but show a persistent increase over the sample period.

3.3 Real Exchange Rates, Relative Prices and Productivity

Tables 4 and 5 report the results of panel regressions on real exchange rates and various definitions of relative prices, as well as real exchange rates and productivity. A basic prediction of the Balassa-Samuelson model, captured also by the decomposition in (2.7), is that there should be positive relationship between the aggregate real exchange rate and the ratio of non-traded to traded goods prices. Table 4 indicates that this relationship is quite robust in the data for the Eurozone countries. Moreover, this holds both for the pooled regressions, as well as the regressions with fixed or random effects. In fact for the time series and cross section relationships between q and p_n are very close to one another.

The second panel of Table 4 explores the relationship between the traded goods real exchange rate and the relative price of non-traded goods, captured by the expression (2.8). In the presence of distribution costs in the traded goods sector (i.e. $\kappa < 1$), this relationship should be positive. We see that this is true in the Eurozone data.

In the third panel, the one-to-one relationship between the traded goods real exchange rate and the overall real exchange rate, which is the second expression on the right hand side of (2.7), is strongly supported in both time series and cross section.

Table 5 reports the regression results for the real exchange rate and aggregate productivity, sectoral productivity, and the measure of unit labor costs. In the pooled regressions, there is a strong negative relationship between aggregate productivity and real exchange rates: an increase in the relative productivity of traded to nontraded goods is associated with an appreciation of the real exchange rate. Allowing for the separate effects of traded and non-traded productivity gives clear intuitive results; the real exchange rate is negatively related to traded goods productivity and positively related to non-traded goods productivity. With the separate inclusion of the ULC variable, both of these effects are highly significant. In addition, ULC has a very significant positive effect on Eurozone real exchange rates. Since ULC is measured by the European average relative to the country measure, this implies that a rise in a country's ULC in the Eurozone is associated with a real appreciation. Looking at the time series correlations alone (i.e. focusing on the fixed effects or random effects results), the significance of the relative productivity term is lost, but the significant relationship between the real exchange rate and sectoral productivity levels remains once the ULC variable is incorporated, as suggested by the condition in (2.12). Thus, in the time series as well as the pooled regressions, the real exchange rate for the Eurozone is significantly negatively (positively) related to traded goods (non-traded goods) productivity, and significantly positively related to ULC.

The cross-section results for the Eurozone countries also generally support the importance of traded good productivity and ULC. Countries with higher traded goods productivity have higher (more appreciated) real exchange rates, as do countries with higher unit labor costs.

4 Model Determined Real Exchange Rates under Alternative Exchange Rate Regimes

We now return to the model. The aim is to describe the real exchange rate under fixed exchange rates, comparing the properties of the simulated real exchange rates to those we observe for the sample of Eurozone countries.

4.1 Model Calibration

To construct a valid comparison, we need to appropriately calibrate and simulate the model. Table 6 lists the calibration values. Here we discuss the choice of parameters.

We set both γ, the share of consumption spent on traded goods, and κ, the share of consumption of each traded good composite that is the actual traded product (as opposed to the distribution service), equal to 0.5. The smaller these parameters, the stronger the Balassa-Samuelson effect. These parameter values roughly correspond to what others in the literature have used. The elasticity of substitution between home and foreign retail goods, λ, is set at 8, which is Corsetti et al. (2010) choice [12]. For smaller λ , real exchange rate volatility increases. But larger values tend to make the Balassa-Samuelson effect stronger.

We set ω, the weight on home goods in the composite consumption for traded goods, equal to 0.5, implying no home bias for traded goods. The presence of non-traded goods in consumption and distribution services already imparts a considerable degree of home bias in the overall composition of consumption. We set α, the elasticity of labor in the production function, equal to one [13] . The parameter, σ, the coefficient of relative risk aversion, is set to equal to 2. We set ψ, the Frisch elasticity of labor

[12] Corsetti et. al. (2010) show that this translates into a lower elasticity of substitution between traded wholesale goods, due to the presence of distribution services.

[13] A linear labor technology is a standard assumption in the open macro literature, and as regards the cross section representation of the model, linearity in labor is a long-run equilibrium property of a model with endogenous capital accumulation and an interest rate determined by a constant subjective rate of time preferences.

supply, equal to 1. The elasticity of substitution between the physical good and the distribution service, ϕ is set to 0.25 [14].

The elasticity of substitution between traded and non-traded goods, is θ, is set to 0.7. In addition, β, the discount factor, set equal to 0.99 for quarterly data.

The model has three different kinds of shocks; productivity shocks in each of the two sectors, A_{it}, $i = H, N$, and shocks to the disutility of labor χ_t. The foreign country has a similar pattern of productivity and labor disutility shocks. We set the serial correlation of all productivity shocks equal to 0.9. This roughly matches the serial correlation in productivity shocks in the data. We have no clear evidence on serial correlation in the χ_t process, so for concreteness, we assume this has the same persistence as the productivity shocks.

The standard deviations of productivity shocks is set to 0.014, which again roughly matches the data. This implies a quarterly variance of 0.002. Then if productivity were literally a random walk the variance of annual data would be 0.008, which implies a standard deviation of around 0.09, roughly in line with the data. Again, in the absence of better information, the standard deviations of shocks to the disutility of labor supply are also set to 0.014.

As explained below, our simulation model produces cross section as well as time series observations on real exchange rates. We wish to match the cross sectional standard deviation of productivity in the data. To do this, we allow the long run mean of traded goods productivity to differ among countries, and have a cross section standard deviation of 0.12, as in the data. However, as we see below this assumption on the cross-sectional standard deviation of productivity does not generate enough cross-sectional variance of real exchange rates. So we also let the disutility of work take on the same standard deviation, perfectly correlated with traded goods productivity. Increases in both traded goods productivity and in the disutility of labor supply work toward pushing up the price level. Traded productivity pushes up the price level through the Balassa-Samuelson effect, and χ does so by pushing up the steady-state

[14] Corsetti et al. (2010) set this equal to zero. The argument for a low elasticity of substitution is that wholesale goods have to be purchased in fixed supply to obtain a given amount of retail goods, so there is almost no ability to substitute between the distribution services and the wholesale goods themselves in retail production.

real wage. For the stochastic part of the shocks to disutility of work and productivity, we assume zero correlation [15].

The speed of adjustment of prices in traded and non-traded sectors is set equal to 0.10 per quarter. We did not find that allowing the two speeds to be different mattered very much in the simulations. This parametrization helps to match the persistence of real exchange rates in the data. While this persistence is slightly greater than the persistence assumption that is based on the Bils-Klenow (2004) estimates, it is more in line with more recent work that has found more price stickiness at the micro level than Bils and Klenow found.

For the monetary policy rule, we set σ_p equal to 2. This follows the parametrization of Steinsson (2008).

4.2 Simulation Results

We construct a panel sample of real exchange rates to match the size of the panels in the data. That is, we compute a panel of 10 countries over 15 periods. Countries differ based on their steady state real exchange rates. As discussed in the previous subsection, we assume differences in productivity in traded goods and non-traded goods and disutility of labor is such that the range of real exchange rates within the panel matches the standard deviation across countries within the observed panel. We construct separate fixed and floating exchange rate panels.

We first describe the characteristics of the real exchange rate under completely flexible prices, using the same parameterization and the same shock processes.

As in the discussion of data, we focus on the properties of the overall real exchange rate, and the components of the real exchange rate driven by the internal relative prices, and the relationship between real exchange rates, relative productivity, and relative unit labor costs.

Table 7 illustrates the properties of real exchange rates under fully flexible prices,

[15] Roughly speaking, we justify assuming high correlation in the cross-section but low correlation in the time series on the following grounds: In the long-run, high productivity countries are rich, and therefore prefer more leisure, because leisure is a luxury good. But in the short run, unions or government policy may act to push up wages and reduce hours, so that in the time series productivity and disutility of work are not correlated.

in the cross section and time series. As in the data, everything is reported at annual frequency. The time series standard deviation is 4 percent, while that in the cross section is 10 percent, similar to that in the data. The persistence of the real exchange rate is very close to that in the data. The second panel of Table 7 shows that under flexible prices, real exchange rates are highly correlated with the cross-country relative price of non-traded goods, both in cross section and time series.

How do real exchange rates behave in a model with sticky prices? Table 7 also illustrates the properties of the model simulations with sticky prices. We find in fact that the real exchange rate behaves in a manner very close to the model with fully flexible prices. The standard deviation in time series and cross section is very close to that of the flexible price model, and close to the data, as is the persistence of the real exchange rate. Likewise, the relationship between the real exchange rate and relative price of non-traded goods is almost the same as in the flexible price model.

In the empirical section above, we saw that Eurozone exchange rates are significantly related to sectoral productivities, both in time series and cross-section, and separately, positively associated with measures of unit labor cost. Using the model simulations, we can run the identical regressions as those of the data. Table 8 illustrates the results, for both the flexible price model simulations as well as the fixed exchange rate case. The empirical estimates from Table 5 are repeated, for comparison purposes. In the flexible price model, sectoral productivity shocks drive real exchange rates very much as in the standard Balassa-Samuelson mechanism. Both in cross-section and time-series, an improvement in traded goods productivity generates an appreciation, while an improvement in non-traded goods productivity leads to real exchange rate depreciation. The magnitude of responses in the real exchange rate is approximately equal for both shocks - a one percent increase in traded goods productivity leads to a 0.2 percent real exchange rate appreciation in time series, and about a 0.6 percent appreciation in cross-section. In both cases, a rise in the unit-labor cost parameter leads to a real appreciation. The signs of these estimates match those of the empirical estimates, and the point estimate on traded goods productivity matches the empirics exactly, although the magnitudes differ somewhat for some of the other coefficients.

How are these results changed in the case of sticky prices? Table 8 also reports the sticky price model estimates, under fixed exchange rates. Unlike the results of Table 7, where in the time series moments, there was little difference between the flexible price and sticky price model, we see that the presence of sticky prices does affect the response of the real exchange rate to productivity shocks. The response to traded goods productivity shocks is dampened somewhat, and the response to non-traded goods shocks is enhanced. But still, the sign of the response is the same as under flexible prices, and in fact is closer to the empirical estimates. In addition, the presence of sticky prices reduces considerably the response of the real exchange rate to unit labor cost shocks, and moves the estimate much closer to that in the time-series data.

Not surprisingly, in the cross section, there is much less difference between the flexible price model and the sticky-price model. Moreover, the cross section relationships in both cases are of the same sign as the empirical estimates, and the magnitude of the comparisons are reasonably close.

Overall, these estimates are remarkable for the fact that they indicate that the relationship between real exchange rates and sectoral productivity can be accounted quite well by a standard two-sector New Keynesian model, in a manner which closely resembles the empirical relationship estimated from Eurozone data.

5 Conclusions

We have seen that the real exchange rates in the Eurozone closely reflect differences in the relative prices of nontraded to traded goods across countries, and in turn differences in the relative productivity levels in the traded versus non-traded sectors. The actual pattern of prices and real exchange rates mirrors the pattern produced in the simulations from our model. Moreover, we see in the model simulations that the distribution of real exchange rates in the currency union matches the pattern produced under flexible prices.

Intuitively, there are three main reasons why the real exchange rates in the currency union are so nearly in line with the real exchange rates under flexible prices. First, the initial accession rates in the Eurozone were set in effect to minimize deviations in traded goods prices across countries. So in 1999, the real exchange rates within the Eurozone were effectively initialized at levels that reflect the differences in their nontraded goods prices and differences in distribution costs.

Second, relative productivity shocks over time within the Eurozone simply are not that big. That is, the equilibrium or flexible-price real exchange rate within the Eurozone does not change very much over time. If the initial real exchange rates are near the equilibrium level then even with no further adjustment of the actual real exchange rates, they will not differ too much from the equilibrium rates simply because the equilibrium rates do not stray very far from the initial levels. In a sense, this observation merely restates the point made by Rogoff (1996) in the context of the puzzling behavior of real exchange rates under floating nominal rates. He said that real exchange rate volatility we observe among floating rate countries is impossible to explain if only real productivity shocks drove real exchange rates - that monetary and financial factors must play a role: "existing models based on real shocks cannot account for short-term exchange rate volatility" (p. 648). Equilibrium real exchange rates are not very volatile, and since the currency union eliminates relative monetary shocks, the real exchange rate under a currency union is also not very volatile.

Third, nominal prices do adjust over time, so even in a currency union there is real exchange rate adjustment. It is worth emphasizing that the choice of exchange rate regime only matters for real exchange rate adjustment because nominal prices are sticky. The speed of adjustment of real exchange rates is limited only by the speed of adjustment of nominal prices. While the point is obvious, it still is often overlooked. For example, it is frequently argued that the Eurozone is a poor candidate for a currency union because labor is not very mobile within the Eurozone. But the degree of labor mobility can only matter for the choice of exchange-rate regime if mobility can substitute for nominal wage and price adjustment. That is, labor immobility may well mean that adjustment to real shocks in the Eurozone is slower than in the U.S. where labor is more mobile. However, this refers to an equilibrium adjustment – the problem would exist in the Eurozone even if prices and wages were flexible. Put another way, labor mobility can substitute for nominal exchange rate adjustment only if labor moves at higher frequencies than prices and wages adjust.

References

[1] S. Basu, J. Fernald, N. Oulton, and S. Srinivasan. *NBER Macroeconomics Annual 2003*, chapter The case of the missing productivity growth: or, does information technology explain why productivity accelerated in the United States but not in the United Kingdom?, pages 9–63. MIT Press, 2004.

[2] Paul R. Bergin, Reuven Glick, and Alan M. Taylor. Productivity, tradability, and the long-run price puzzle. *Journal of Monetary Economics*, 53, 2006.

[3] Martin Berka and Michael B. Devereux. Trends in European real exchange rates. *Economic Policy*, 28(74):193–242, April 2013.

[4] Caroline Betts and Timothy J. Kehoe. U.S. real exchange rate fluctuations and relative price fluctuations. *Journal of Monetary Economics*, 33, 2006.

[5] Mark Bils and Peter J. Klenow. Some evidence on the importance of sticky prices. *Journal of Political Economy*, 112(5):947–985, October 2004.

[6] Ariel Burstein, Martin Eichenbaum, and Sergio Rebelo. Large devaluations and the real exchange rate. *Journal of Political Economy*, 113, 2005.

[7] Ariel Burstein, Joao C. Neves, and Sergio Rebelo. Distribution costs and real exchange rate dynamics during exchange-rate-based stabilizations. *Journal of Monetary Economics*, 50:1189–1214, September 2003.

[8] Matthew B. Canzoneri, Robert E. Cumby, and Behzad Diba. Relative labor productivity and the real exchange rate in the long run: evidence from a panel of OECD countries. *Journal of International Economics*, 47, 1996.

[9] D. W. Caves, L. R. Christensen, and W. E. Diewert. Multilateral comparisons of output, input and productivity using superlative index numbers. *The Economic Journal*, 92(365):73 – 86, 1982.

[10] Menzie Chinn and Louis Johnson. Real exchange rate levels, productivity and demand shocks: evidence from a panel of 14 countries. Working Paper 5709, NBER, 1996.

[11] Yangping Chong, Òscar Jordà, and Alan M. Taylor. The Harrod-Balassa-Samuelson hypothesis: real exchange rates and their long-run equilibrium. *International Economic Review*, 53(2):609–633, 2012.

[12] Giancarlo Corsetti, Luca Dedola, and Sylvain Leduc. Optimal monetary policy in open economies, in Handbook of Monetary Economics, eds.: Benjamin M. Friedman and Michael Woodford. Volume 3:281–305, 2010.

[13] Giancarlo Corsetti and Paolo Pesenti. International dimension of optimal monetary policy. *Journal of Monetary Economics*, 52:281 – 305, 2005.

[14] Michael B. Devereux and Charles Engel. Monetary policy in the open economy revisited: Exchange rate flexibility and price setting behaviour. *Review of Economic Studies*, 70:765–783, 2003.

[15] Charles Engel. Accounting for US real exchange rate changes. *Journal of Political Economy*, 130(3):507–538, June 1999.

[16] Charles Engel. Currency misallignments and optimal monetary policy. *American Economic Review*, 101:2796–2822, 2011.

[17] Charles Engel and John H. Rogers. European product market integration after the euro. *Economic Policy*, 39:349–384, July 2004.

[18] Jesus Felipe and Ustav Kumar. Unit labor costs in the Eurozone: the competitiveness debate again. Levy Economic Institute, Working paper no. 651, 2011.

[19] Jose De Gregorio, Alberto Giovannini, and Holger C. Wolf. International evidence on tradables and nontradables inflation. *European Economic Review*, 38(6):1225–1244, June 1994.

[20] C. R. Hulten. *New Developments in Productivity Analysis, Studies in Income and Wealth*, volume 63, chapter Total factor productivity: a short biography, pages 1–47. University of Chicago Press, 2001.

[21] Robert Inklaar and Marcel P. Timmer. GGDC productivity level database: International comparisons of output, inputs and productivity at the industry level. Discussion Paper GD-104, University of Groningen Growth and Development Centre, 2008.

[22] D. W. Jorgenson, M. S. Ho, and K. J. Stiroh. *Information Technology and American Growth Resurgence*. MIT Press, 2005.

[23] D. W. Jorgenson and M. Nishmizu. U.S. and Japanese economic growth, 1952-1974: An international comparison. *The Economic Journal*, 88:707–726, 1978.

[24] James R. Lothian and Mark P. Taylor. Real exchange rates over the past two centuries: how important is the Harrod-Balassa-Samuelson effect? *The Economic Journal*, 118:1742–1763, 2008.

[25] Michael Mussa. Nominal and real exchange rate regimes and the behavior of real exchange rates: evidence and implications. *Carnegie-Rochester Conference Series on Public Policy*, 25, 1986.

[26] Mary O'Mahony and Marcel P. Timmer. Output, input and productivity measures at the industry level: The EU KLEMS database. *The Economic Journal*, 119:F374–F403, June 2009.

[27] Kenneth Rogoff. The purchasing power parity puzzle. *Journal of Economic Literature*, (34):647–668, 1996.

[28] Stephanie Schmitt-Grohe and Martin Uribe. Pegs and pain. Working Paper, Department of Economics, Columbia University, 2011.

[29] Jon Steinsson. The dynamic behaviour of real exchange rates in sticky price models. *American Economic Review*, 98:519 – 33, 2008.

[30] Josip Tica and Ivo Družić. The Harrod-Balassa-Saumelson effect: A survey of empirical evidence. Working Paper 06-7/686, University of Zagreb, 2006.

6 Tables

Table 1. PLI basic headings, Household expenditures

T	Rice	T	Major tools and equipment
T	Other cereals, flour and other cereal products	T	Small tools and miscellaneous accessories
T	Bread	T	Non-durable household goods
T	Other bakery products	NT	Domestic services
T	Pasta products	NT	Household services
T	Beef and Veal	T	Pharmaceutical products
T	Pork	T	Other medical products
T	Lamb, mutton and goat	T	Therapeutical appliances and equipment
T	Poultry	NT	Medical Services
T	Other meats and edible offal	NT	Services of dentists
T	Delicatessen and other meat preparations	NT	Paramedical services
T	Fresh, chilled or frozen fish and seafood	NT	Hospital services
T	Preserved or processed fish and seafood	T	Motor cars with diesel engine
T	Fresh milk	T	Motor cars with petrol engine of cubic capacity of less than 1200cc
T	Preserved milk and other milk products	T	Motor cars with petrol engine of cubic capacity of 1200cc to 1699cc
T	Cheese	T	Motor cars with petrol engine of cubic capacity of 1700cc to 2999cc
T	Eggs and egg-based products	T	Motor cars with petrol engine of cubic capacity of 3000cc and over
T	Butter	T	Motor cycles
T	Margarine	T	Bicycles
T	Other edible oils and fats	T	Animal drawn vehicles
T	Fresh or chilled fruit	T	Spare parts and accessories for personal transport equipment
T	Frozen, preserved or processed fruit	T	Fuels and lubricants for personal transport equipment
T	Fresh or chilled vegetables other than potatoes	NT	Maintenance and repair of personal transport equipment
T	Fresh or chilled potatoes	NT	Other services in respect of personal transport equipment
T	Frozen, preserved or processed vegetables	NT	Passenger transport by railway
T	Sugar	NT	Passenger transport by road
T	Jams, marmalades and honey	NT	Passenger transport by air
T	Confectionery, chocolate and other cocoa preps	NT	Passenger transport by sea and inland waterway
T	Edible ice, ice cream and sorbet	NT	Combined passenger transport
T	Coffee, tea and cocoa	NT	Other purchased transport services
T	Mineral waters	NT	Postal services
T	Soft drinks and concentrates	T	Telephone and telefax equipment
T	Fruit and vegetable juices	NT	Telephone and telefax services
T	Spirits	T	Equipment for reception, recording and reproduction of sound and pictures
T	Wine	T	Photographic and cinematographic equipment and optical instruments
T	Beer	T	Information processing equipment
T	Tobacco	T	Pre-recorded recording media
T	Narcotics	T	Unrecorded recording media
T	Other clothing and clothing accessories	NT	Repair of audio-visual, photographic and information processing equipment
T	Clothing materials	T	Major durables for outdoor recreation
T	Men's clothing	T	Musical instruments and major durables for indoor recreation
T	Women's clothing	NT	Maintenance and repair of other major durables for recreation and culture
T	Childrens and infants clothing	T	Games, toys and hobbies
T	Other clothing and clothing accessories	T	Equipment for sport, camping and open-air recreation
NT	Cleaning, repair and hire of clothing	T	Gardens, plants and flowers
T	Men's footwear	T	Pets and related products
T	Women's footwear	T	Veterinary and other services for pets
T	Children's and infant's footwear	NT	Recreational and sporting services
NT	Repair and hire of footwear	NT	Photographic services
NT	Actual rentals for housing	NT	Other cultural services
NT	Imputed rentals for housing	T	Games of chance
T	Materials for maintenance and repair of dwelling	T	Books
NT	Services for maintenance and repair of dwelling	T	Newspapers and periodicals
T	Water supply	T	Miscellaneous printed matter, stationery and drawing materials
NT	Miscellaneous services relating to the dwelling	T	Package holidays
T	Electricity	NT	Pre-primary and primary education
T	Gas	NT	Secondary education
T	Liquid fuels	NT	Post-secondary education
T	Solid fuels	NT	Tertiary education
T	Heat energy	NT	Education not definable by level
T	Kitchen furniture	NT	Restaurant services whatever the type of establishment
T	Bedroom furniture	NT	Pubs, bars, cafs, tea rooms and the like
T	Living-room and dining-room furniture	NT	Canteens
T	Other furniture and furnishings	NT	Accommodation services
T	Carpets and other floor coverings	NT	Hairdressing salons and personal grooming establishments
NT	Repair of furniture, furnishings and floors	T	Electric appliances for personal care
T	Household textiles	T	Other appliances, articles and products for personal care
T	Major household appliances electric or not	NT	Prostitution
T	Small electric household appliances	T	Jewellery, clocks and watches
NT	Repair of household appliances	T	Other personal effects
T	Glassware, tableware and household utensils	NT	Social protection
		NT	Insurance
		NT	Other financial services n.e.c.
		NT	Other services n.e.c.

Table 2. Country summary statistics

country	$\overline{q}$	$\overline{q_T}$	$\overline{q_N}$	$\overline{pn}$	s(q)	s(q_T)	s(q_N)	s(pn)	$\overline{a_T}$	$\overline{a_N}$	$\overline{a_T - a_N}$	s(a_T)	s(a_N)	s($a_T - a_N$)
BE	0.00	0.01	-0.01	-0.02	0.03	0.02	0.03	0.02	-0.05	-0.03	-0.03	0.04	0.04	0.02
GER	-0.01	0.02	-0.04	-0.06	0.04	0.02	0.07	0.07	-0.02	-0.08	0.06	0.01	0.01	0.02
GRE	0.20	0.16	0.25	0.09	0.03	0.03	0.05	0.03						
SPA	0.17	0.16	0.17	0.01	0.02	0.02	0.03	0.03	0.12	-0.02	0.14	0.10	0.05	0.05
FRA	-0.03	0.02	-0.08	-0.10	0.03	0.03	0.03	0.02	-0.01	-0.07	0.06	0.02	0.02	0.02
IRE	-0.11	-0.09	-0.12	-0.04	0.08	0.05	0.10	0.05	-0.25	-0.03	-0.22	0.05	0.02	0.05
ITA	0.05	0.02	0.09	0.07	0.04	0.04	0.04	0.02	0.03	0.10	-0.08	0.10	0.04	0.07
LUX	-0.01	0.08	-0.13	-0.21	0.04	0.03	0.06	0.06						
NET	0.02	0.03	0.00	-0.03	0.02	0.02	0.03	0.03	-0.13	-0.23	0.09	0.02	0.03	0.05
AUS	0.02	0.00	0.03	0.04	0.03	0.03	0.04	0.01	0.05	-0.01	0.06	0.06	0.02	0.04
POR	0.20	0.11	0.33	0.21	0.01	0.02	0.02	0.03						
FIN	-0.16	-0.12	-0.19	-0.07	0.03	0.03	0.03	0.01	-0.20	-0.16	-0.05	0.08	0.04	0.05
SWE	-0.13	-0.10	-0.16	-0.06	0.07	0.05	0.10	0.06	-0.09	-0.05	-0.04	0.11	0.02	0.09
DEN	-0.24	-0.24	-0.24	0.00	0.03	0.02	0.04	0.04	0.08	-0.18	0.25	0.08	0.02	0.07
UK	0.00	-0.01	0.00	0.01	0.09	0.09	0.10	0.03	0.00	-0.03	0.04	0.04	0.02	0.05
ICE	-0.21	-0.23	-0.19	0.04	0.12	0.12	0.14	0.07						
NOR	-0.26	-0.30	-0.21	0.09	0.04	0.04	0.05	0.02						
SWI	-0.27	-0.12	-0.36	0.25	0.06	0.05	0.07	0.03						
CYP	0.14	0.05	0.24	0.19	0.01	0.02	0.02	0.03						
CZE	0.57	0.36	0.87	0.51	0.13	0.12	0.15	0.05	0.17	0.24	-0.07	0.05	0.05	0.06
EST	0.45	0.33	0.64	0.31	0.10	0.07	0.15	0.09						
HUN	0.54	0.37	0.81	0.44	0.11	0.10	0.13	0.04	0.15	0.26	-0.11	0.07	0.06	0.02
LAT	0.54	0.37	0.81	0.44	0.11	0.09	0.16	0.08						
LIT	0.56	0.41	0.95	0.53	0.09	0.08	0.14	0.06						
MAL	0.28	0.13	0.45	0.32	0.03	0.03	0.05	0.05						
POL	0.56	0.41	0.78	0.37	0.08	0.09	0.09	0.06						
SVK	0.65	0.42	1.01	0.58	0.18	0.17	0.23	0.06						
SVN	0.30	0.19	0.45	0.26	0.03	0.03	0.05	0.03	0.16	0.28	-0.12	0.05	0.03	0.07
BUL	0.86	0.58	1.23	0.64	0.12	0.12	0.11	0.03						
ROM	0.74	0.57	1.06	0.49	0.16	0.17	0.18	0.05						
TUR	0.57	0.38	0.89	0.52	0.11	0.10	0.21	0.13						

All real exchange rate variables are expressed as EU15 average relative to home country. q is the expenditure-weighted log real exchange rate (an increase is a depreciation). q_T (q_N) is the real exchange rate for traded (nontraded) goods only, both relative to EU15 average (again, an increase is a depreciation). $pn \equiv q_N - q_T$. $s(.)$ denotes standard deviation. RER sample is 1995 - 2009 (annual), except for the countries of Southern and Eastern Europe (from Cyprus onwards), where the sample begins in 1999. a_T (a_N) is a logarithm of traded (nontraded) TFP of EU12 relative to home country. Traded is an aggregate of 1-digit sector's TFP levels aggregated using sectoral gross outputs as weights. TFP sample is 1995 - 2007 for all countries with data.

Table 3. Standard deviations

variable	mean(std_i(.)) All	EZ	Float	East	std($mean_i$(.)) All	EZ	Float	East
q	0.067	0.033	0.070	0.098	0.328	0.113	0.103	0.193
q_T	0.061	0.028	0.060	0.091	0.238	0.087	0.109	0.154
q_N	0.088	0.044	0.084	0.129	0.471	0.158	0.120	0.275
pn	0.045	0.032	0.043	0.059	0.253	0.107	0.119	0.133
a_T	0.059	0.055	0.075	0.055	0.129	0.121	0.083	0.014
a_N	0.031	0.031	0.019	0.045	0.155	0.093	0.078	0.017
$a_T - a_N$	0.049	0.040	0.070	0.052	0.119	0.111	0.151	0.027

All real exchange rate variables are expressed relative to EU15 average (=0 each year). q is the expenditure-weighted log real exchange rate (increase is a depreciation). q_T (q_N) is the same real exchange rate but for traded (nontraded) goods only, both relative to EU15 average (increase is a depreciation)$pn \equiv q_N - q_T$. RER sample is 1995 - 2009 (annual), except for the countries of Southern and Eastern Europe, where the sample begins in 1999. a_T (a_N) is a logarithm of traded (nontraded) TFP relative to EU12. Traded constitutes an aggregate of 1-digit sector's TFP levels aggregated using sectoral gross outputs as weights. TFP sample is 1995 - 2007 for all countries with data (see previous Table).

The left panel reports average time series standard deviation (std_i(.), where i indexes countries). The right panel reports the standard deviation of average real exchange rates ($mean_i$(.), where $_i$ indexes countries).

Table 4. Price regressions

	q			
	1	2	3	4
	Pool	FE	RE	XS
pn	**0.70***	**0.60***	**0.61***	**0.71**
	(0.058)	(0.076)	(0.07)	(0.247)
$\overline{R}^2$	0.44	0.93	0.36	0.40
N	180	180	180	12
HT	–	–	not reject	–

	pn			
	9	10	11	12
	Pool	FE	RE	XS
$\mathbf{q_T}$	**0.39***	0.17	**0.19*	0.42
	(0.086)	(0.11)	(0.103)	(0.26)
$\overline{R}^2$	0.10	0.89	0.02	0.03
N	180	180	180	12
HT	–	–	not reject	–

	q			
	17	18	19	20
	Pool	FE	RE	XS
$\mathbf{q_T}$	**1.19***	**1.08***	**1.09***	**1.20***
	(0.038)	(0.053)	(0.048)	(0.11)
$\overline{R}^2$	0.84	0.98	0.77	0.83
N	180	180	180	12
HT	–	–	not reject	–

q is the logarithm of expenditure-weighted real exchange rate EU15 average relative to country i (an increase is a depreciation). q_T is the logarithm of the expenditure-weighted real exchange rate of tradables in EU15 on average, relative to country i (an increase is a depreciation). pn is the log of the relative price of nontraded to traded goods (all expenditure-weighted) in EU15 on average, relative to country i ($pn \equiv q_N - q_T$). *Pool* is a pooled regression with all countries and years sharing the same estimate of a constant and a slope. FE is a fixed-effects panel regression with countries as cross sections. RE is a random effects regression with countries as cross sections. XS is a cross-sectional regression which uses time-average values of variables in each country. All standard errors are computed using a panel adjustment robust to serial correlation (except for XS, where Newey-West adjustment is used). Standard errors in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Eurozone countries are: Austria, Belgium, Germany, Greece, France, Finland, Italy, Ireland, Luxembourg, the Netherlands, Portugal, and Spain. Rejection of the null at 5% in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table 5. RER - TFP regression

	Pool			Fixed effects			Random effects			Cross-section		
	1a	1b	1c	2a	2b	2c	3a	3b	3c	4a	4b	4c
TFP	**0.43*****	–	–	-0.10	–	–	-0.04	–	–	**0.51****	–	–
	(0.067)			(0.11)			(0.094)			(0.21)		
TFP_T	–	**0.50*****	**0.76*****	–	0.003	**0.18****	–	0.05	**0.26*****	–	**0.67*****	**0.93*****
		(0.059)	(0.062)		(0.11)	(0.090)		(0.09)	(0.079)		(0.145)	(0.19)
TFP_N	–	-0.09	**-0.29*****	–	**-0.36***	**-0.36****	–	**-0.29***	**-0.36*****	–	-0.05	-0.27
		(0.08)	(0.078)		(0.22)	(0.18)		(0.164)	(0.13)		(0.184)	(0.22)
ULC	–	–	**0.42*****	–	–	**0.46*****	–	–	**0.46*****	–	–	**0.43***
			(0.079)			(0.072)			(0.077)			(0.20)
$\overline{R}^2$	0.25	0.41	0.57	0.84	0.85	0.90	-0.007	0.02	0.32	0.28	0.62	0.76
N	117	117	117	117	117	117	117	117	117	9	9	9
HT	–	–	–	–	–	–	reject	reject	reject			

Dependant variable: log real exchange rate (expenditure-weighted) expressed as EU15 average relative to country i (an increase is a *depreciation*). TFP_i is the log of TFP level of traded relative to non-traded sector in EU12 ($\log(TFP_{T,EU12,t}/TFP_{N,EU12,t})$) relative to country i. $TFP_{T,i,t}$ is an aggregation of 1-digit sectoral TFP of traded sectors (agriculture is excluded due to issues caused by Common Agricultural Policy) using sectoral outputs as weights. ULC_{it} comes from OECD.Stat database and is defined as a ratio of nominal Total Labor Costs for the economy relative to real output (2005 base year). We convert ULC_{it} to euro for all countries. ULC in EU 17 (provided by OECD) relative to country i (an increase is a depreciation) is used in regressions. *Pool* is a pooled regression with all countries and periods sharing the same estimate of a constant and slope. Fixed effects is a panel regression with countries as cross-sections. Random effects is a random effects panel with countries as cross sections. Cross-section is a regression which uses the time-average value for each country and runs a cross sectional regression. All standard errors (except in $Cross-section$) are computed using a Panel corrected standard errors method (Beck and Katz, 1995) under the assumption of period correlation (cross-sectional clustering). The standard errors in $Cross-section$ are Newey-West standard errors. Standard errors in parentheses. The estimate of the constant is not reported. A * denotes a 10%, ** 5% and *** 1% significance. Included Eurozone members are: Austria, Belgium, Germany, Finland, France, Ireland, Italy, the Netherlands and Spain. Rejection of the null in Hausman test (HT) implies no difference between FE and RE, viewed as a preference for FE.

Table 6. Calibration

		Households	
Share of C on traded goods	γ	0.5	
Share of wholesale traded goods in C_T	κ	0.5	
E.O.S. between H and F retail Traded goods	λ	8	Corsetti et al. (2010)
E.O.S. between traded good and retail service	ϕ	0.25	
E.O.S. between traded and nontraded goods	θ	0.7	
Weight on H goods in C_T	ω	0.5	No home bias
Coefficient of relative risk aversion	σ	2	
Frisch elasticity of labor supply	ψ	1	
Discount factor	β	0.99	
		Firms	
Elasticity of labor in Y	α	1	
Autocorrelation of A	ρ_A	0.9	data
Autocorrelation of χ	ρ_χ	0.9	
Time-series standard deviation of ϵ_{At}	$\sigma\epsilon_{At}$	0.014	data
Time-series standard deviation of ϵ_{χ_t}	$\sigma\epsilon_{\chi_t}$	0.014	
Cross-sectional standard deviation of ϵ_{A_i}	$\sigma\epsilon_{A_i}$	0.12	data
Cross-sectional standard deviation of ϵ_{χ_i}	$\sigma\epsilon_{\chi_i}$	0.12	
Speed of Calvo price adjustment		0.10/quater	Bils and Klenow (2004)
		Monetary policy	
		Fixed exchange rate	
Weight on nominal exchange rate targeting	σ_s	large	To ensure fixed ER
		Floating exchange rate	
Weight on nominal exchange rate targeting	σ_s	0	Steinsson (2008)
Weight on inflation targeting	σ_p	2	Steinsson (2008)
Weight on real exchange rate targeting	σ_q	0.5	Steinsson (2008)
Autocorrelation of monetary shock u_t	ρ_u	0.99	
Standard deviation of monetary shock u_t	σ_u	0.12, 0.08, 0.07	To match std(q) in the data (differs for PCP, LCP)
Fraction priced in LCP and PCP in mixed regime	ν	0.5	

Table 7. Properties of model Real Exchange Rates

	Fixed - sticky	Flexible prices	Data
	1	2	3
STD (Time Series)	0.037 (0.030, 0.042)	0.042 (0.036, 0.050)	0.033
STD (Cross Section)	0.101 (0.071, 0.125)	0.106 (0.085, 0.131)	0.113
Serial Correlation	0.794 (0.720, 0.880)	0.663 (0.570, 0.759)	0.670

Regression of Real Exchange Rate on Relative Nontraded Price

	4	5	6
Time series	1.606 (1.567, 1.628)	1.586 (1.558, 1.617)	0.70
Cross section	0.942 (0.791, 1.052)	0.967 (0.877, 1.068)	0.60

Description

Table 8.
Regression of Real Exchange Rates on Productivity and ULC

	Fixed - sticky	Flexible prices	Data
Time Series			
	1	2	3
Traded TFP	0.131 (0.162, 0.065)	0.185 (0.201, 0.169)	0.18
Nontraded TFP	-0.512 (-0.423,-0.580)	-0.194 (-0.155,-0.218)	-0.36
ULC	0.421 (0.284, 0.580)	1.399 (1.320, 1.470)	0.46
Cross Section			
	4	5	6
Traded TFP	0.601 (0.662, 0.498)	0.588 (0.654, 0.545)	0.93
Nontraded TFP	-0.410 (-0.015,-1.150)	-0.581 (-0.143,-0.955)	-0.27
ULC	0.831 (-0.364, 1.608)	0.597 (-0.128, 1.471)	0.43

Description

7 Figures

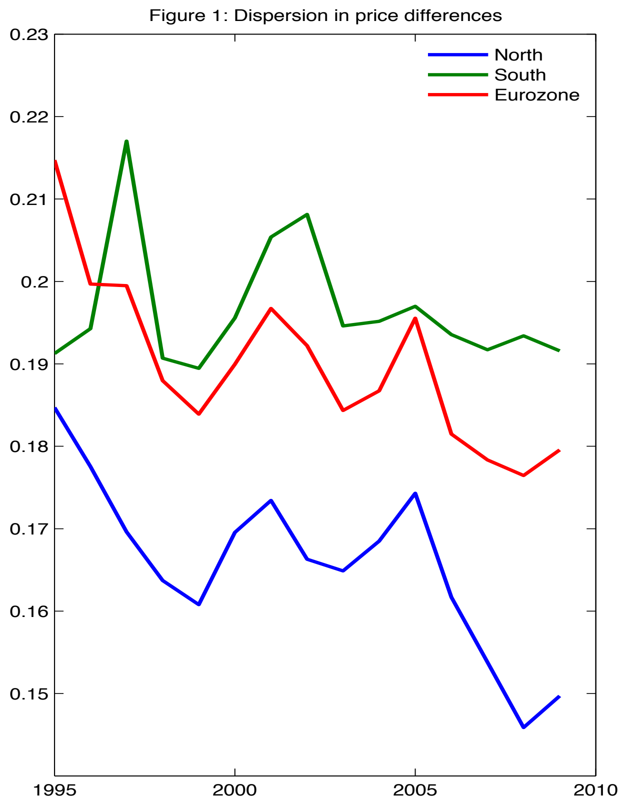


Figure 1: Dispersion in price differences
North
South
Eurozone
0.23
0.22
0.21
0.2
0.19
0.18
0.17
0.16
0.15
1995
2000
2005
2010

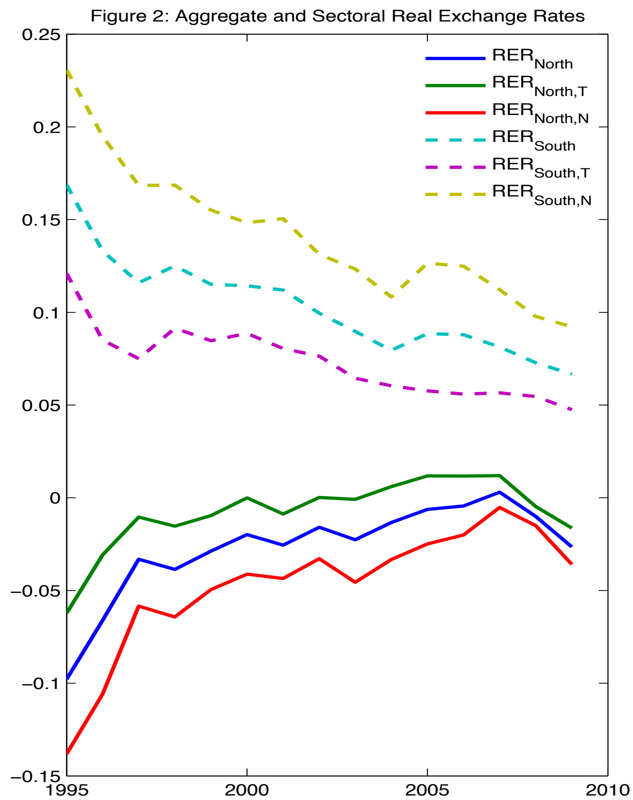
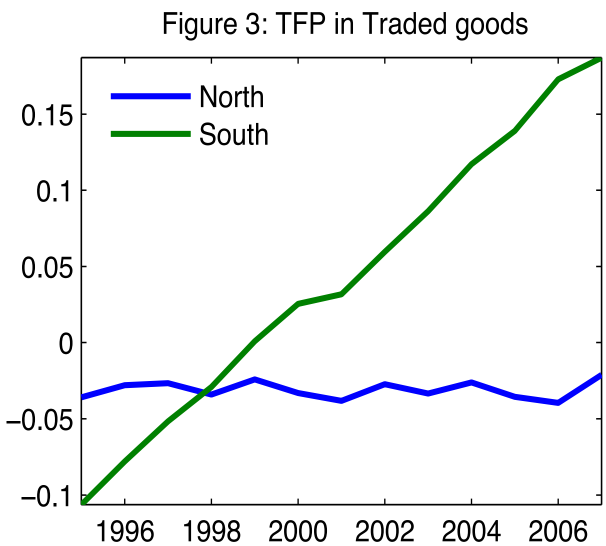
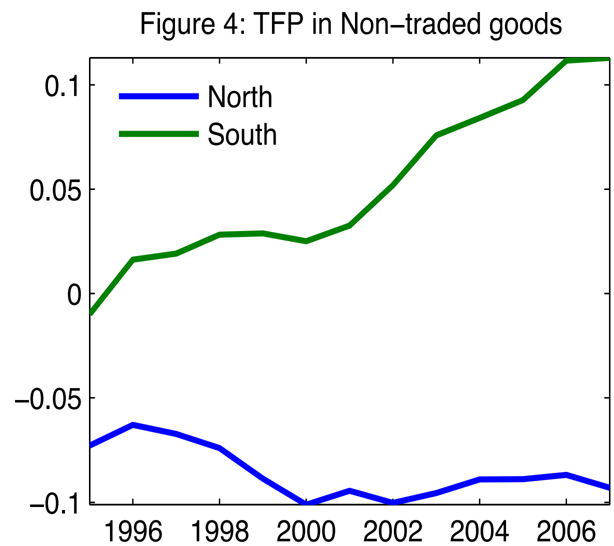
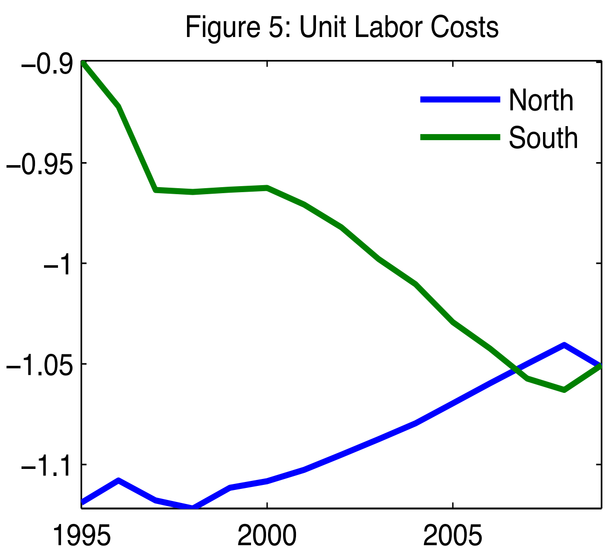


Figure 2: Aggregate and Sectoral Real Exchange Rates
RER_{North}
$RER_{North,T}$
$RER_{North,N}$
RER_{South}
$RER_{South,T}$
$RER_{South,N}$
0.25
0.2
0.15
0.1
0.05
0
−0.05
−0.1
−0.15
1995
2000
2005
2010







Figures 3, 4 and 5 use GDP-weighted average values of TFP in the respective sectors. The measure of GDP is Eurostat's "nama_gdp_k", GDP volume at market prices in 2005 euro. The weights are calculated annually.

A Appendix: Construction of the panel of sectoral TFP levels across Europe

This section documents the construction of the TFP level panel dataset at sectoral level. The reason for the construction of this dataset to provide the perfect match to the level data of real exchange rates across Europe. To construct the dataset, we construct a concordance between the sectors included in the Groningen Growth and Development Center's (GGDC thereafter) 1997 TFP level database, and the sectors included in the KLEMS time-series database. These two databases are meant to be used in conjunction, as outlined in Inklaar and Timmer (2008). Then, the cross-sectional TFP database and the time-series TFP database are linked using the constructed concordance to obtain annual sectoral panel TFP level data.

Table A1 lists the sectors included in the TFP 1997 level database and Table A2 the sectors in the TFP time-series sectoral growth rate database. Table A3 shows the concordance between the two, the names of the 21 overlapping sectors, and their tradability descriptor.

A.1 1997 TFP levels

The construction of the 1997 GDDC TFP level database[16] is described in Inklaar and Timmer (2008) (IT thereafter). The database is constructed for 30 OECD countries using an improved version of the methodology of Jorgenson and Nishmizu (1978)[17]. We use the output-based measure of TFP which IT argue better reflects technology differences than the two other value-added measures (see IT pp. 23).

TFP 1997 level estimates are constructed vis-à-vis the U.S. levels in two stages. First, symmetric Input-Output Tables and input PPPs are constructed for 45 sub-industries. The second stage consists of two steps. First, PPPs for capital, labor and intermediate inputs for 29 industries (based on 45 sub-industries) are constructed using a price-variant of index number approach in Caves et al. (1982) known as the CCD method. These are used to implicitly derive quantities of all inputs and outputs. The second step, known as primal level accounting, sees industry comparative productivity levels constructed on the basis of input and output quantities in a bilateral Tornqvist model as in Jorgenson and Nishimizu (1978). Specifically, for sector i in

[16]See `http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database`.

[17]The improvements include the use of sectoral IO measures that exclude intra-industry flows, the application of multilateral indices at the industry level, and the use of relative output prices from the production side and the use of the exogenous approach to capital measurement.

country j in 1997, IT estimate the level of sectoral TFP as:

$$\ln A_{i,j} \equiv \ln TFP_{i,j}^{SO} = \ln \frac{Q_{i,j}^{SO}}{Q_{i,US}^{SO}} - \hat{\nu}_K \ln \frac{Q_{i,j}^{K}}{Q_{i,US}^{K}} - \hat{\nu}_L \ln \frac{Q_{i,j}^{L}}{Q_{i,US}^{L}} - \hat{\nu}_{II} \ln \frac{Q_{i,j}^{II}}{Q_{i,US}^{II}} \quad \text{(A.13)}$$

where Q_j^K is a quantity index of capital services, Q_c^L is a quantity index of labor services and Q_j^{II} is a quantity index of intermediate input services. $\hat{\nu}_K$ is the share of capital services in total costs averaged over the two countries: $\hat{\nu}_K = 0.5(\nu_j^K + \nu_j^{US})$ where $\nu_j^K \equiv \frac{V_j^K}{V_j^K + V_j^L + V_j^{II}}$ and V_j^K is the nominal value of capital services. In order to facilitate quantity measure comparisons, $Q_j^{SO} = \frac{V_j^{SO}}{PPP_j^{SO}}$ where V_j^{SO} is the nominal value of output in country j. Similarly for intermediate inputs Q_j^{II}. For labor input Q_j^L, the same ratio measure is justified by the need to aggregate various labor types (high- vs. low-skill), and the construction of PPP_j^L which is constructed based on relative wages. For capital input, $Q_j^K = \frac{\tilde{V}_j^K}{PPP_j^K}$ where $\tilde{V}_j^K$ is the ex-ante nominal compensation of capital $\tilde{V}_j^K = V_j^K - V_j^R$ where V_j^R is "supra-normal profits" (see IT section 4.1 for a detailed discussion).

A.2 TFP time series

A European Commission-funded project, EU KLEMS data contains annual observations for 25 European countries, Japan and the US from 1970 onwards. The data is described in detail in O'Mahony and Timmer (2009, OT thereafter). We use KLEMS' Total factor productivity growth March 2011 update to the November 2009 release[18]. The TFP is estimated in the growth accounting approach as a measure of disembodied technological change[19]. The growth accounting in KLEMS proceeds under standard neoclassical assumptions of constant returns to scale and perfect competition[20] allows a full decomposition of industry i output:

$$\begin{aligned} \Delta \ln Y_{it} \;=\; & \bar{\nu}_{it}^X \bar{\omega}_{it}^E \Delta \ln X_{it}^E + \bar{\nu}_{it}^X \bar{\omega}_{it}^M \Delta \ln X_{it}^M + \bar{\nu}_{it}^X \bar{\omega}_{it}^S \Delta \ln X_{it}^S \\ & + \bar{\nu}_{it}^K \bar{\omega}_{it}^{ICT} \Delta \ln K_{it}^{ICT} + \bar{\nu}_{it}^K \bar{\omega}_{it}^N \Delta \ln K_{it}^N \\ & + \bar{\nu}_{it}^L \Delta \ln LC_{it} + \bar{\nu}_{it}^L \Delta \ln H_{it} + \Delta \ln B_{it}^Y \end{aligned} \quad \text{(A.14)}$$

where Y is output, K is an index of capital service flows, L is an index of labor service flows, X is an index of intermediate inputs, H is hours worked, LC is labor

[18]See http://www.euklems.net/euk09ii.shtml.

[19]Technical change embodied in new capital goods is excluded from TFP due to the KLEMS' use of quality-adjusted prices.

[20]Consequently, negative TFP growth can be observed in some service industries, which OT is a consequence of well-known measurement issues surrounding corporate reorganization and institutional changes (see Basu et al. 2004 and Hulten, 2001).

composition[21] and B is an index of disembodied (Hicks-neutral) technological change. Intermediate inputs are further split into energy (E), materials (M) and services (S), each with a respective period-average share $\bar{\omega}$ in total input costs. Each of the inputs K, L, X^E, X^M, X^S is constructed as a Törnqvist quantity index of individual subtypes ($\Delta \ln I_{it} = \sum_l \bar{\omega}^I_{l,it} \Delta \ln I_{l,it}$). $\bar{\nu}$ are two-period average shares of each input in the nominal output.

A.3 Construction of the TFP level sectoral panel dataset

The construction of TFP level sectoral panel dataset proceeds in four steps. First, the sectors in the 1997 cross-section dataset are matched to the sectors in the TFP growth-rate dataset. Second, a level TFP series is constructed for each sector and country. Third, TFP level is expressed relative to EU12 average, to match the construction of the real exchange rate dataset as closely as possible[22]. Fourth, the sectors are aggregated into Traded and Nontraded aggregates using sectoral output data.

Let A_{ij} be the 1997 GDDC sectoral-output and PPP based TFP of sector i in country j, relative to the US. Let B_{ijt} be the EU KLEMS sectoral-output and PPP based TFP index of sector i in country j and year t, re-scaled so that $B_{i,j,1997} = 100\ \forall i, j$. Both A and B are synchronized to the 21 sectors as in Table A3. Let also $B_{i,US,t}$ be the TFP index for each sector in the US, also with the base of 100 in 1997. Then, sectoral TFP level C_{ijt} is constructed as:

$$C_{ijt} = \frac{A_{ij} B_{ijt}}{B_{i,US,t}} \tag{A.15}$$

and similarly for the EU15 aggregate:

$$C_{i,EU12,t} = \frac{A_{i,EU12} B_{i,EU12,t}}{B_{i,US,t}} \tag{A.16}$$

The TFP level index expressed vis-a-vis EU12. It is the ratio of (3) and (4):

$$TFP_{ijt} = \frac{C_{ijt}}{C_{i,EU12,t}} = \frac{A_{ij} B_{ijt}}{A_{i,EU12} B_{i,EU12,t}} \tag{A.17}$$

The aggregate traded and nontraded TFP levels are computed as follows:

$$TFP_{T,j,t} = \frac{\sum_{i \in T} \gamma_{ij,T} C_{ijt}}{\frac{1}{12} \sum_{j \in EU12} (\sum_{i \in T} \gamma_{i,j,T} C_{i,j,t})} \tag{A.18}$$

[21] Labor composition is growth literature's measure of "labor quality" (see Jorgenson et al. 2005). It consists of labor characteristics such as educational attainment, age and gender.

[22] Only 12 of the EU15 countries have TFP data: Belgium, Germany, Spain, France, Ireland, Italy, the Netherlands, Austria, Finland, Sweden, Denmark and the United Kingdom.

$$TFP_{N,j,t} = \frac{\sum_{i \in N} \gamma_{ij,N} C_{ijt}}{\frac{1}{12}\sum_{j \in EU12}(\sum_{i \in N} \gamma_{i,j,N} C_{i,j,t})} \tag{A.19}$$

where $\gamma_{ij,T}$ ($\gamma_{ij,N}$) is a 1997 sectoral output weight of sector i in traded (nontraded) output of country j (s.t., $\sum_i \gamma_{ij} = 1 \ \forall j$). The agriculture sector is omitted from the analysis because of the EU's Common Agricultural Policy's distortion of many assumption used to calculate sectoral TFP measures.

Consequently, the relative productivity measure in Traded to Nontraded sectors is constructed as a ratio of (5) and (6). In our empirical analysis we always work with the logarithms of these constructed productivity measures.

Table A1. Sectors in the GGDC 1997 TFP level database

1	TOTAL INDUSTRIES
2	MARKET ECONOMY
3	ELECTRICAL MACHINERY, POST AND COMMUNICATION SERVICES
4	Electrical and optical equipment
5	Post and telecommunications
6	GOODS PRODUCING, EXCLUDING ELECTRICAL MACHINERY
7	TOTAL MANUFACTURING, EXCLUDING ELECTRICAL
8	Consumer manufacturing
9	Food products, beverages and tobacco
10	Textiles, textile products, leather and footwear
11	Manufacturing nec; recycling
12	Intermediate manufacturing
13	Wood and products of wood and cork
14	Pulp, paper, paper products, printing and publishing
15	Coke, refined petroleum products and nuclear fuel
16	Chemicals and chemical products
17	Rubber and plastics products
18	Other non-metallic mineral products
19	Basic metals and fabricated metal products
20	Investment goods, excluding hightech
21	Machinery, nec.
22	Transport equipment
23	OTHER PRODUCTION
24	Mining and quarrying
25	Electricity, gas and water supply
26	Construction
27	Agriculture, hunting, forestry and fishing
28	MARKET SERVICES, EXCLUDING POST AND TELECOMMUNICATIONS
29	DISTRIBUTION
30	Trade
31	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
32	Wholesale trade and commission trade, except of motor vehicles and motorcycles
33	Retail trade, except of motor vehicles and motorcycles; repair of household goods
34	Transport and storage
35	FINANCE AND BUSINESS, EXCEPT REAL ESTATE
36	Financial intermediation
37	Renting of m. eq. and other business activities
38	PERSONAL SERVICES
39	Hotels and restaurants
40	Other community, social and personal services
41	Private households with employed persons
42	NON-MARKET SERVICES
43	Public admin, education and health
44	Public admin and defence; compulsory social security
45	Education
46	Health and social work
47	Real estate activities

`http://www.rug.nl/research/ggdc/data/ggdc-productivity-level-database`

Table A2. Sectors in the March 2009 edition of the KLEMS TFP time-series database

1	TOTAL INDUSTRIES
2	AGRICULTURE, HUNTING, FORESTRY AND FISHING
3	MINING AND QUARRYING
4	TOTAL MANUFACTURING
5	FOOD , BEVERAGES AND TOBACCO
6	TEXTILES, TEXTILE , LEATHER AND FOOTWEAR
7	WOOD AND OF WOOD AND CORK
8	PULP, PAPER, PAPER , PRINTING AND PUBLISHING
9	CHEMICAL, RUBBER, PLASTICS AND FUEL
10	Coke, refined petroleum and nuclear fuel
11	Chemicals and chemical
12	Rubber and plastics
13	OTHER NON-METALLIC MINERAL
14	BASIC METALS AND FABRICATED METAL
15	MACHINERY, NEC
16	ELECTRICAL AND OPTICAL EQUIPMENT
17	TRANSPORT EQUIPMENT
18	MANUFACTURING NEC; RECYCLING
19	ELECTRICITY, GAS AND WATER SUPPLY
20	CONSTRUCTION
21	WHOLESALE AND RETAIL TRADE
22	Sale, maintenance and repair of motor vehicles and motorcycles; retail sale of fuel
23	Wholesale trade and commission trade, except of motor vehicles and motorcycles
24	Retail trade, except of motor vehicles and motorcycles; repair of household goods
25	HOTELS AND RESTAURANTS
26	TRANSPORT AND STORAGE AND COMMUNICATION
27	TRANSPORT AND STORAGE
28	POST AND TELECOMMUNICATIONS
29	FINANCE, INSURANCE, REAL ESTATE AND BUSINESS SERVICES
30	FINANCIAL INTERMEDIATION
31	REAL ESTATE, RENTING AND BUSINESS ACTIVITIES
32	Real estate activities
33	Renting of m. eq. and other business activities
34	COMMUNITY SOCIAL AND PERSONAL SERVICES
35	PUBLIC ADMIN AND DEFENCE; COMPULSORY SOCIAL SECURITY
36	EDUCATION
37	HEALTH AND SOCIAL WORK
38	OTHER COMMUNITY, SOCIAL AND PERSONAL SERVICES
39	PRIVATE HOUSEHOLDS WITH EMPLOYED PERSONS
40	EXTRA-TERRITORIAL ORGANIZATIONS AND BODIES

http://www.euklems.net/euk09ii.shtml

Table A3. Sectoral concordance

	GGDC sector ID	KLEMS sector ID	Tradability	Names of sectors
1	27	2	T	Agriculture, hunting, forestry and fishing
2	24	3	T	Mining and quarrying
3	9	5	T	Food , beverages and tobacco
4	10	6	T	Textiles, textile , leather and footwear
5	13	7	T	Wood and of wood and cork
6	14	8	T	Pulp, paper, paper , printing and publishing
7	16	9	T	Chemical, rubber, plastics and fuel
8	18	13	T	Other non-metallic mineral
9	19	14	T	Basic metals and fabricated metal
10	21	15	T	Machinery, nec
11	4	16	T	Electrical and optical equipment
12	22	17	T	Transport equipment
13	11	18	T	Manufacturing nec; recycling
14	25	19	N	Electricity, gas and water supply
15	26	20	N	Construction
16	29	21	N	Wholesale and retail trade
17	39	25	N	Hotels and restaurants
18	34	27	N	Transport and storage
19	5	28	N	Post and telecommunications
20	36	30	N	Financial intermediation
21	37	31	N	Real estate, renting and business activities